CFD SIMULATION OF LIQUID ROCKET ENGINE INJECTORS
Part 1. SIMULATIONS OF THE RCM-1 EXPERIMENTS

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In the course of developing a practical CFD model for simulating the many injector elements in a full-scale rocket engine, the wide variation in density and enthalpy was deemed to be of primary importance. The pressure based FDNS CFD code was modified to account for such variations. Very general thermal and caloric equations of state were developed for describing hydrogen, RP-1, and oxygen propellants over the range of pressures and temperatures expected. These thermodynamic equations, as well as the modifications needed to perform pressure iterations, are described in Part 3 of this paper. Such a CFD model would constitute a homogeneous simulation of a spray. While recognizing that this model does not account for thermal and velocity lag between drops and vapor, the model should represent supercritical jet flows very well.

The supericritical cryogenic injection experiments (RCM-1) are exactly the type needed to verify and tune the CFD model. The turbulence model used in the CFD code should be tuned to match appropriate test data. If the turbulence model alone is not adequate to match the data, a finite-rate equation could be used to delay vaporization by approximating inter-phase transport processes. The RCM-1 simulations discussed in the following are our first step in this tuning process.

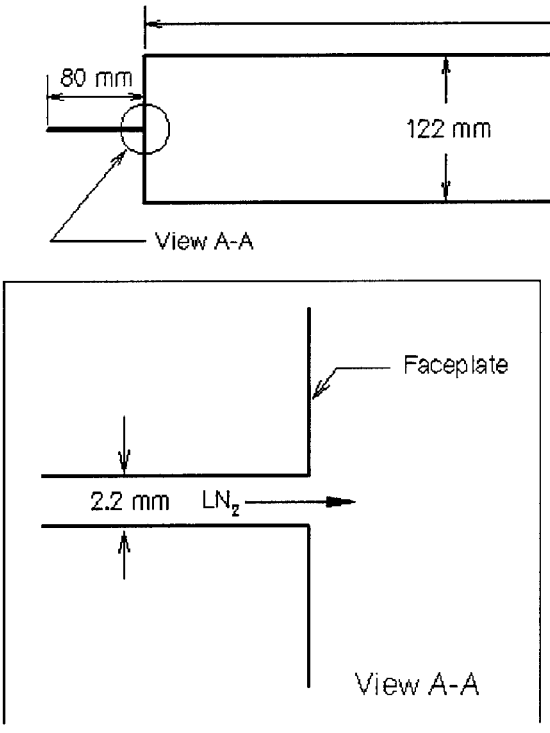
The LN2 cases, RCM-1-A and -B, were simulated with the homogeneous spray model. The flow predicted resembles a dense fluid jet with strong density gradients in the shear layer. Such a flow has been observed in a similar super-critical nitrogen jet experiment reported by Chehroudi, et al[1]. These predictions should compare well to the DLR experimental data. If the comparisons are not good, adjustment of the parameters in the two-equation k-ε or the initial turbulence level parameters could be made for a better fit of the data. Such tuning has not previously been made since appropriate test data were not available. For a definitive analysis of the experiments, conjugate heat transfer to the injector hardware and consideration of the duration of the experiment should be made. The jet is discharging into a gaseous nitrogen environment; the recirculated gas should become slowly cooled until a steady state is reached. Since the temporal variation of the recirculating gas temperature was not reported, the time that the CFD simulation should be terminated can not be determined. Since the measurements were made very close to the injector exit, good simulation of the gas temperature might not be crucially important.

The injector configuration and flow conditions for the cryogenic nitrogen jet of the RCM-1 test cases are illustrated in Fig. 1. It can be seen that the chamber pressure for both cases is above the critical pressure of nitrogen. A 101x11-mesh system was used to discretize the injector section, while the chamber section was modeled by a 301x101-mesh system for Case RCM-1-A.. The same grid system was used to simulate both RCM-1-A and RCM-1-B test cases. The numerical result of RCM-1-A test case at the locations specified by IWRCM was plotted as shown in Figures 2-6.

Notice the temperature profiles in Figure 4. These two cold flow cases are not steady-state, although the simulations assumed this to be the situation. The simulations presented represent a time-slice at some arbitrary time. Figure 7 shows the flowfield near the injector tip. A finer grid system (101x15, and 301x141) was employed to simulate the RCM-1-B. The numerical results of RCM-1-B test case are plotted in Figures 8-12. The flowfield is presented in Fig. 13. Notice that only a small segment of the chamber is shown so that the gradients in the flowfield may be clearly seen.

REFERENCES

1. Chehroudi, B., et al, "Initial Growth Rate and Visual Characteristics of a Round Jet into a Sub- to Supercritical Environment of Relevance to Rocket, Gas Turbine, and Diesel Engines," AIAA 99-0206, 1999.



	Case A	Case B
Chamber Pressure	3.97 MPa	5.98 MPa
Temperature	126.9 °K	128.7 °K
Mass Flow Rate	0.00995 kg/s	0.01069 kg/s
Inlet TKE	0.003 U_{inj}^2	0.003 U_{inj}^2

Critical Pressure of N_2: 3.4 MPa
Critical Temperature of N_2: 126.2 °K
U_{inj}: Injection Velocity of N_2

Figure 1. Configuration of RCM-1 Test Case.

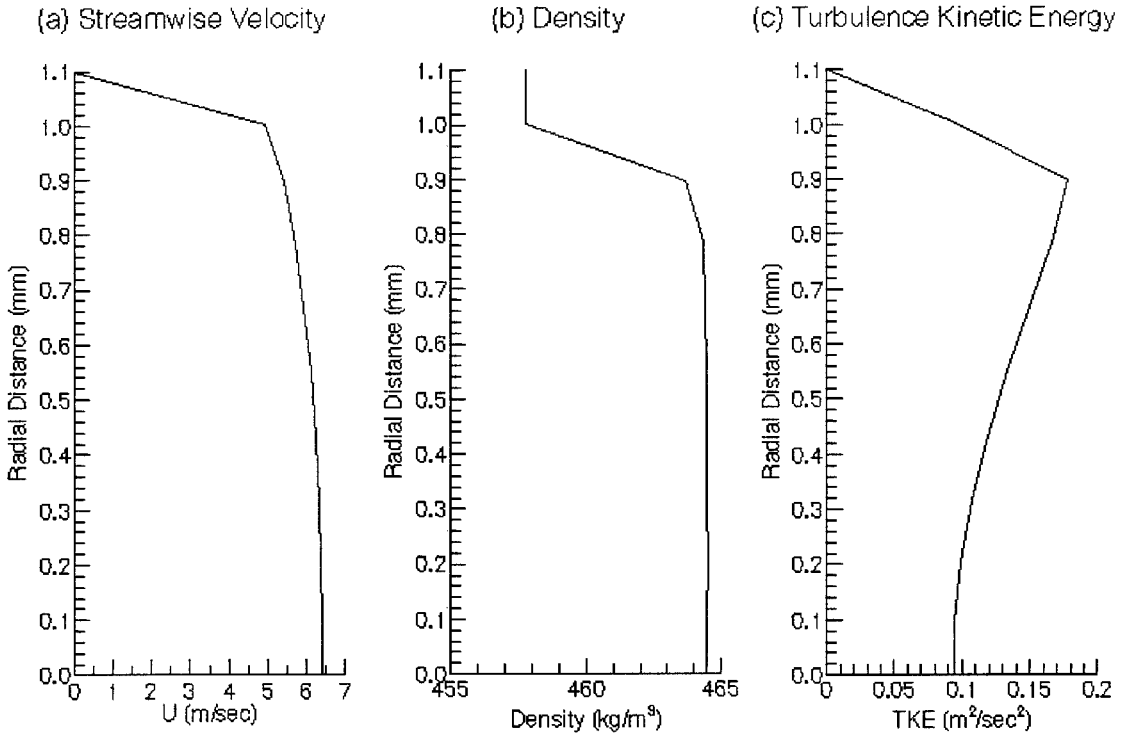


Figure 2. Flow Properties at the Injector Exit of RCM-1-A.

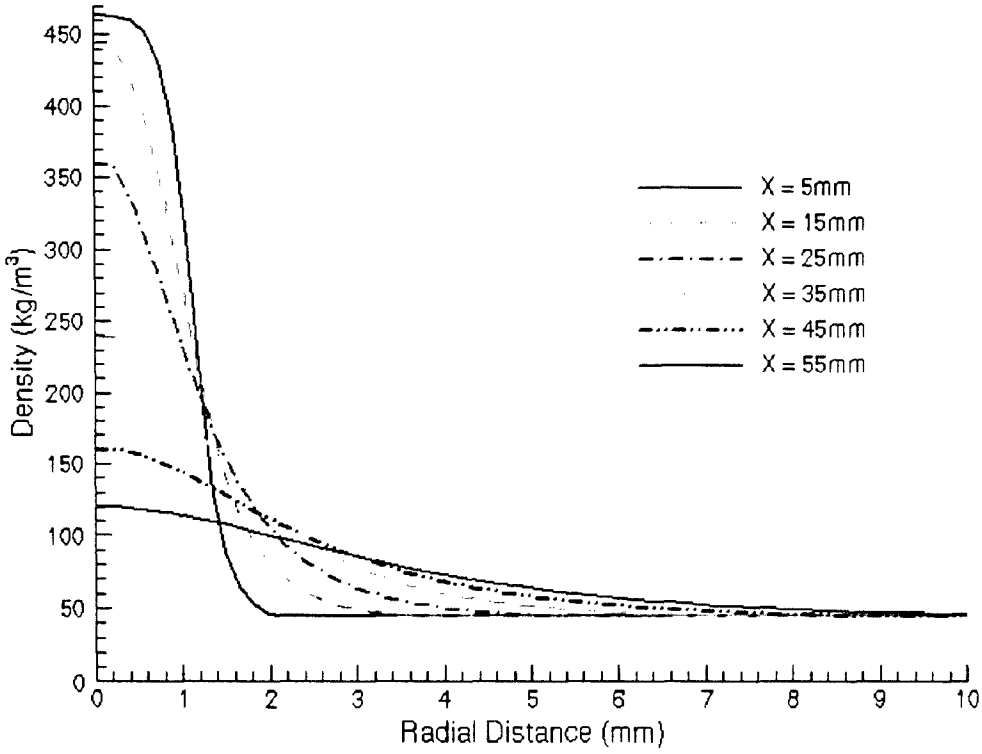


Figure 3. Density Profiles at Various Streamwise Locations of RCM-1-A.

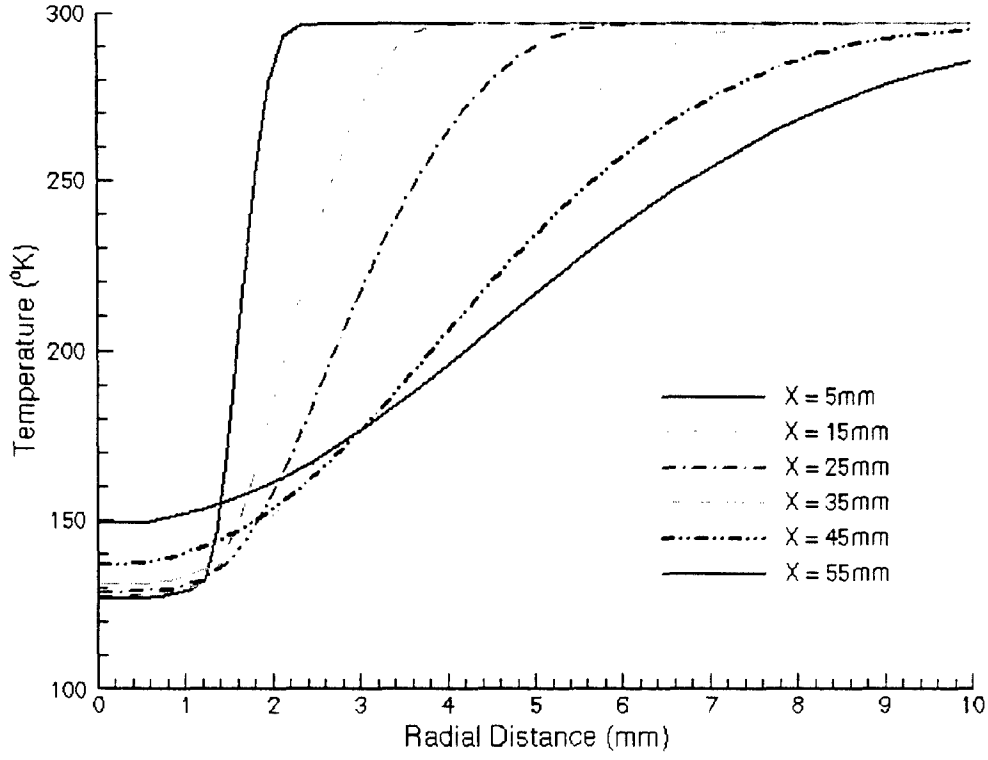


Figure 4. Temperature Profiles at Various Streamwise Locations of RCM-1-A.

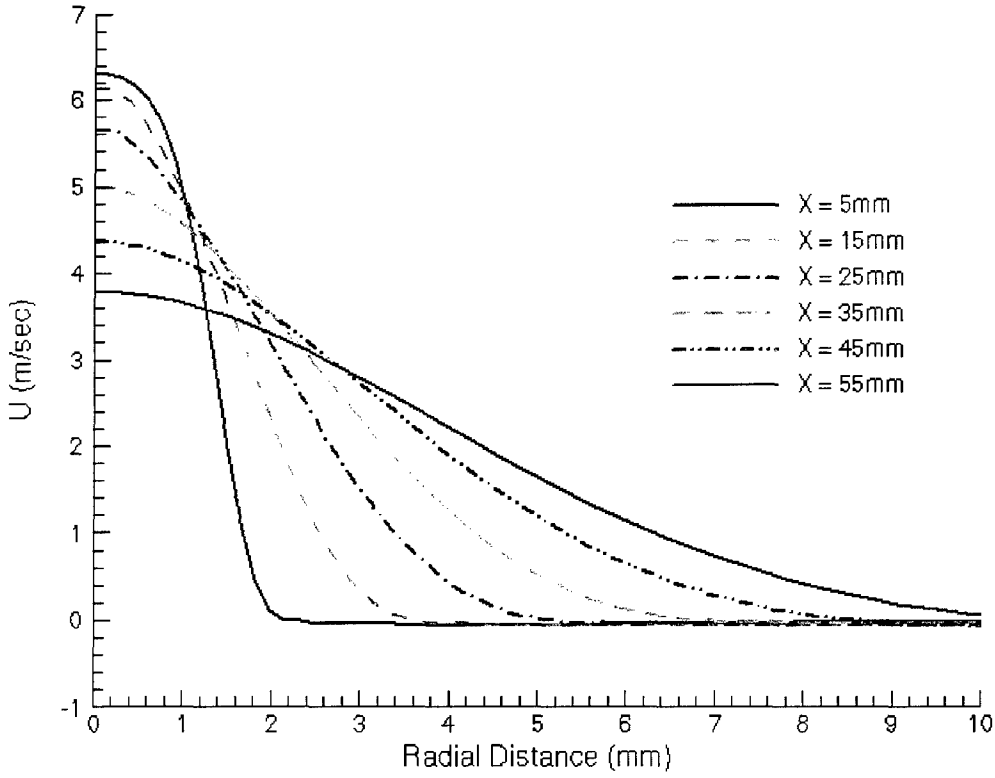


Figure 5. Axial Velocity Profiles at Various Streamwise Locations of RCM-1-A.

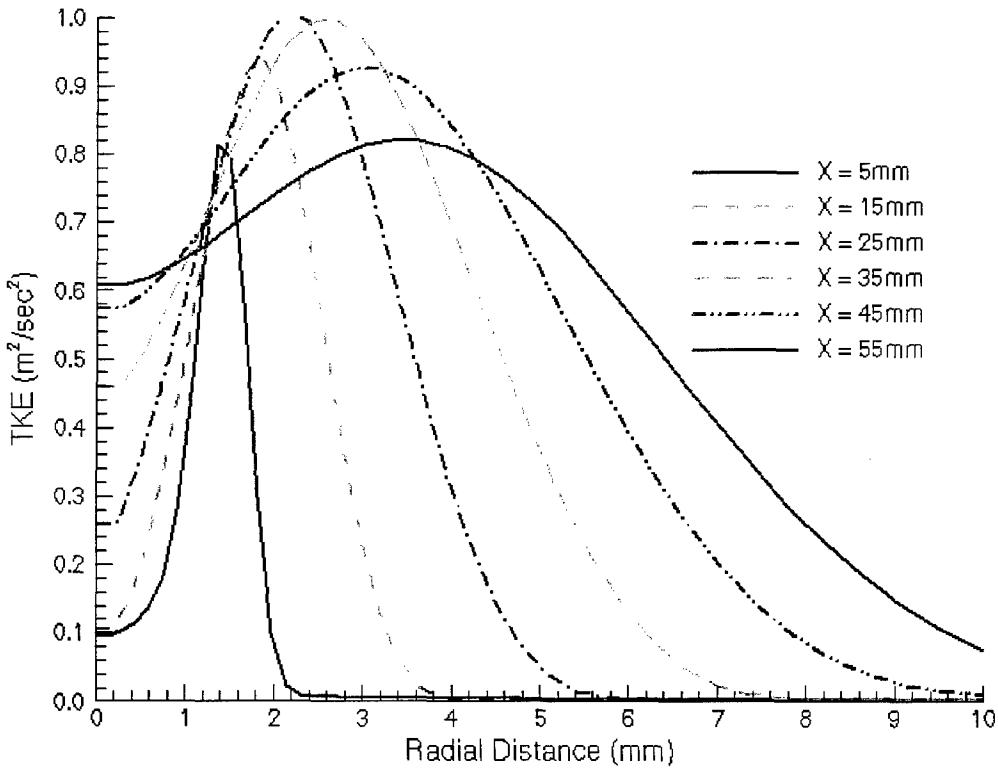


Figure 6. Turbulent Kinetic Energy Profiles at Various Streamwise Locations of RCM-1-A.

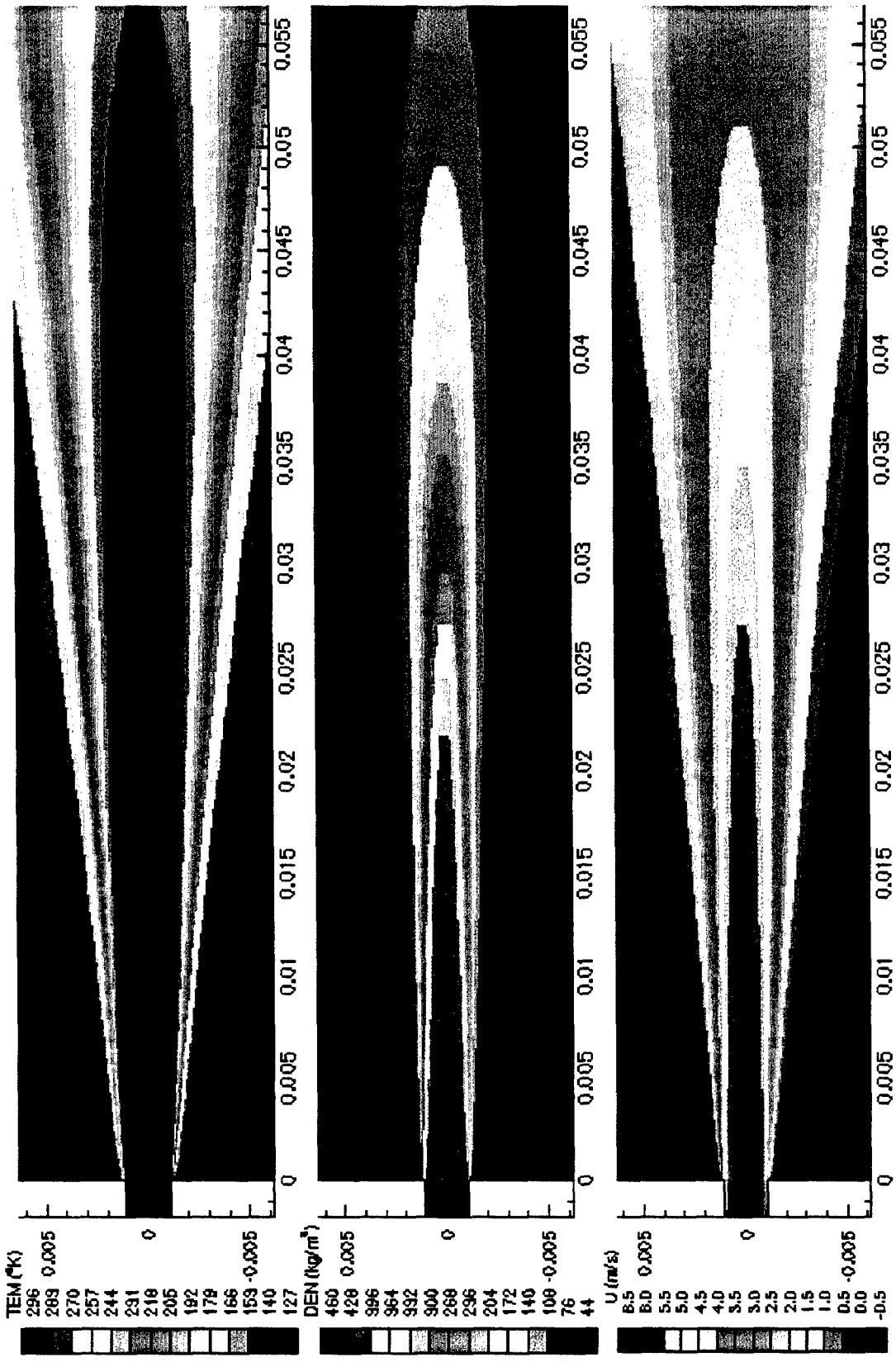


Figure 7. Flow Properties Near the Injector of RCM-1-A.

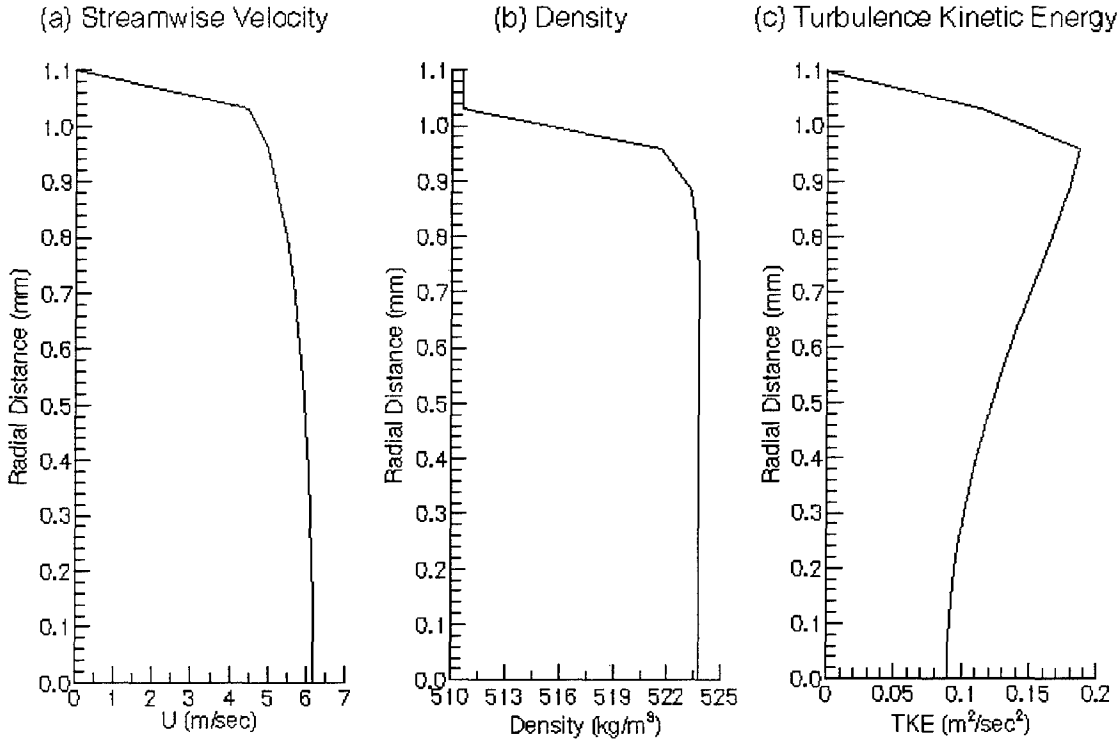


Figure 8. Flow Properties at the Injector Exit of RCM-1-B.

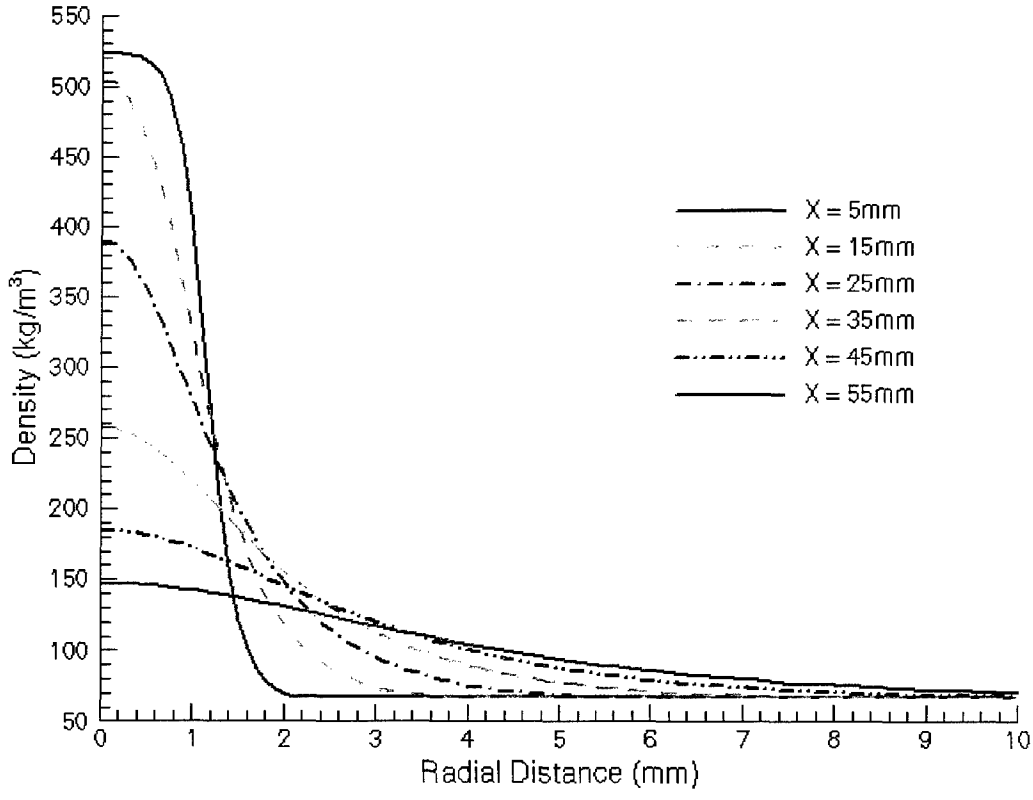


Figure 9. Density Profiles at Various Streamwise Locations of RCM-1-B.

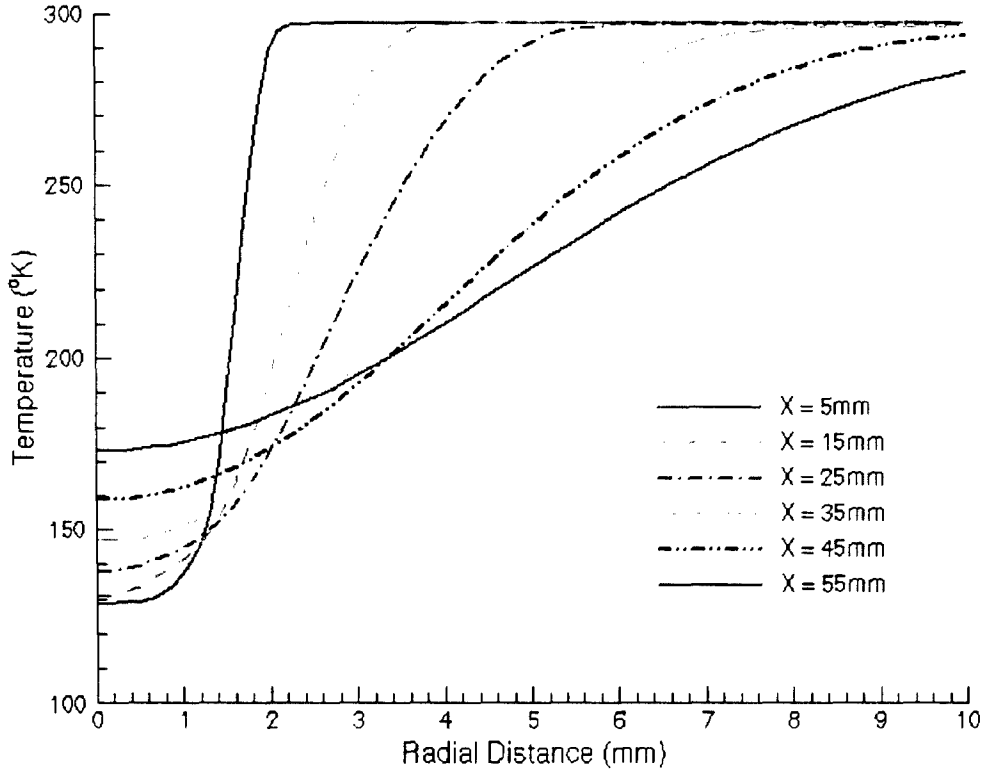


Figure 10. Temperature Profiles at Various Streamwise Locations of RCM-1-B.

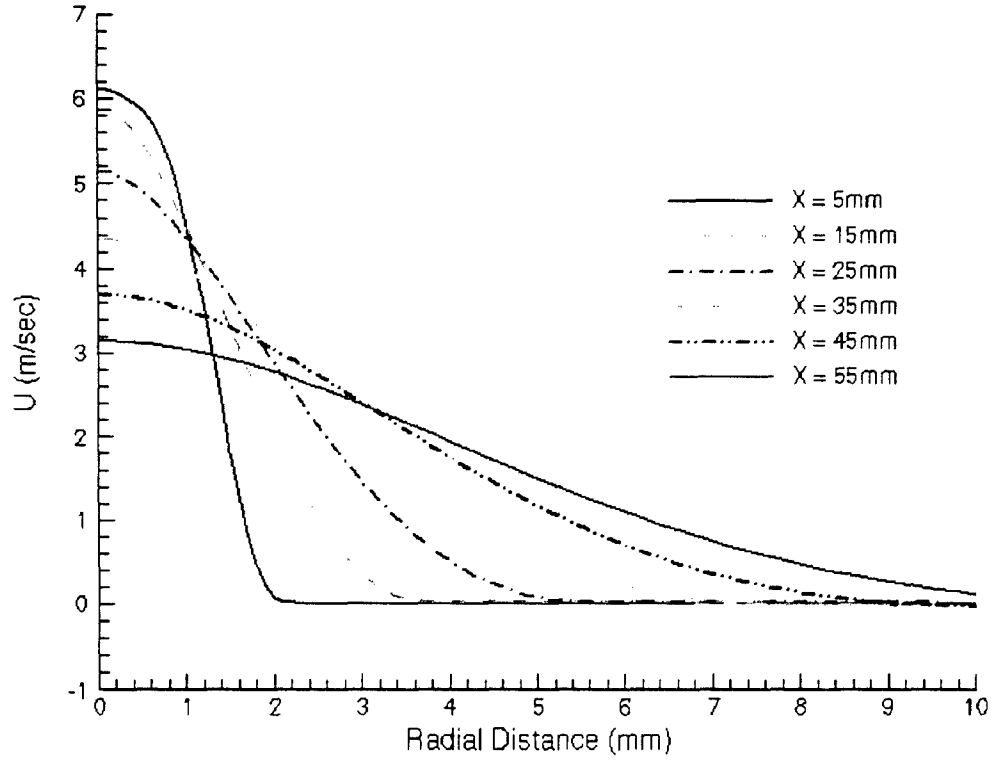


Figure 11. Axial Velocity Profiles at Various Streamwise Locations of RCM-1-B.

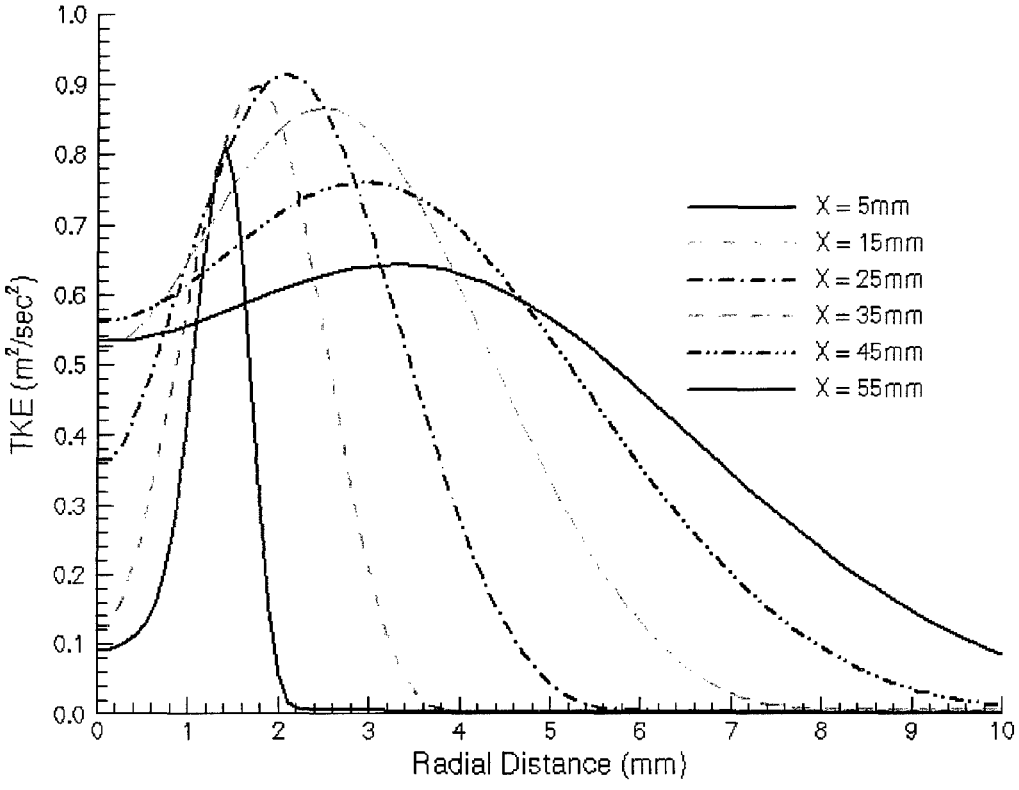


Figure 12. Turbulent Kinetic Energy Profiles at Various Streamwise Locations of RCM-1-B.

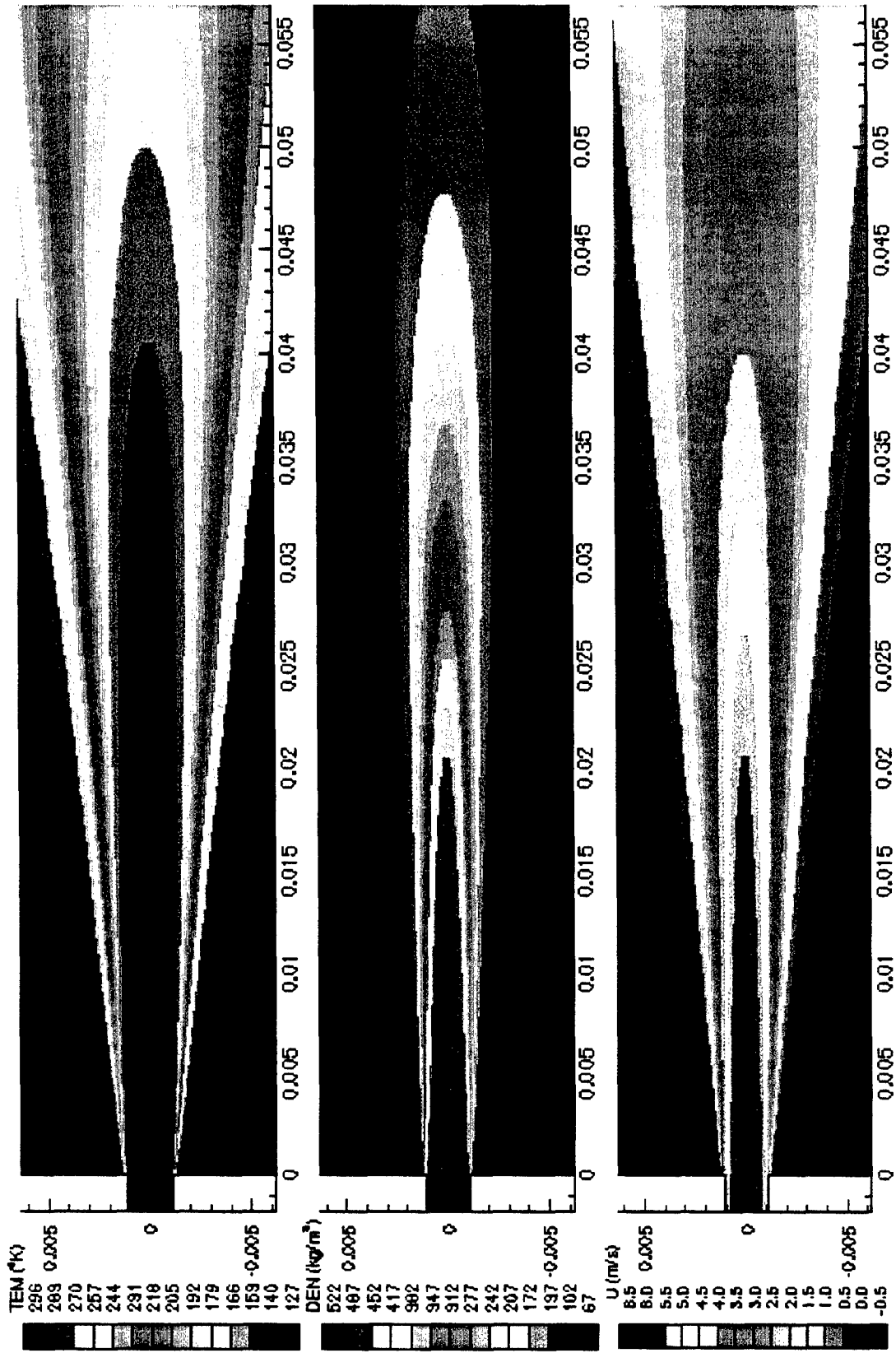


Figure 13. Flow Properties Near the Injector of RCM-1-B.